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ORIGINAL PAPER

Economic analysis on log damage during logging operation in Caspian Forests

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Abstract: Waste wood was studied in an economic enterprise by logging, function, tree species and log size in four Caspian hardwood sites. Damaged logs were recorded with additional information obtained for the location, dimensions and type of damage. The data were analyzed statistically to determine significant differences of damage during logging process. The results indicated that animal harvesting systems cause more volume (40.5% of log volume) and value loss (89.5 $\$\cdot m^{-3}$) to logs than mechanized harvesting systems (13.9% and 6.0 $\$\cdot m^{-3}$), also bucking resulted in significantly more volume (9.9% of log volume) and value loss (5.5 $\$\cdot m^{-3}$) when compared to skidding (0.2% of log volume and 0.2 $\$\cdot m^{-3}$), decking (0.4% of log volume and 0.2 $\$\cdot m^{-3}$) and loading (0.2% of log's volume and 0.3 $\$\cdot m^{-3}$) operations. Study showed that the processes of skidding, decking and loading of logs have very little impact on damage levels. Volume and value losses of damaged logs are not sensitive to tree species and log size. The information from the field study is important in creating new guidelines or training to help minimize hardwood log damage during the timber harvesting process.

Keywords: log damage; forest operations; Caspian hardwood forests

Introduction

The forests in northern Iran are most often logged by one of two methods, mechanized logging with a skidder or traditional logging with a mule. However, the most frequently used extraction method in the region is ground based skidding. The value of forest products from the Caspian hardwood region continues to grow as the demand for quality hardwood lumber increases. In addition, there are substantial increases in demand for veneer type products from hardwood species such as beech *(Fagus orientalis)* and Elm *(Ulmus glabra)*. Previous studies indicate that some log damage can be controlled and significant gains in potential value can be achieved through a log quality control system (Craig 1982). Williston (1979) found that breakage and skidding/yarding damage associated with harvesting operations destroyed almost 6% of the total value of harvested logs. McNeel and Copithorne (1996) stated that species is a factor in defining the amount of breakage expected during harvest. Damage to harvested trees or logs can occur during the felling, bucking, skidding, decking, loading and hauling functions of the timber harvesting process (Wang et al. 2004). McMorland and Guimier (1984) found that shears cause very many but shallow splits, while saw chains cause less frequent but deeper splits. Greene and McNeel (1989), Faust and Greene (1989) reported log damage by feller-bunchers with both shear and saw heads and found that the damage usually occurred in the first 12 inches of the butt log. Even small improvements in value recovery could lead to large improvements in financial gains (Boston and Dysart 2000). Han and Renzie (2005) found that feller-buncher felling results in greater wood volume waste as a results of a thicker saw blade kerf than dose chan saw felling. Wang et al. (2004) found that felling resulted in significantly more log damage when compared to skidding, decking and loading operations. Hall and Han (2006) found that the average stump height by mechanized felling was 5.8cm (17%) lower than that by manual felling, also the potential value loss from manual felling was estimated to be up to 0.33 $/tree more than that from mechanized felling. Unver and Acar (2009) developed a prediction model by considering friction vector affecting skidded log, friction surface area of the log and skidding distance parameter. Improper bucking might not damage the log in a physical sense, but it could damage the potential value gained from bucking correctly (Sessions 1988; Pickens et al. 1992; Zavala 1995). The implementation of correct log bucking procedures can potentially increase the yield from each tree harvested, which correspondingly can improve profits for the logger and sawmill. Dragging the logs over the ground could present some type of potential damage to the harvested logs (Wang et al. 2004). Skidding full-length trees following selection cutting can also contribute to log breakage in certain

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situations, such as when skidding through switchbacks. Skidders or a loader can be used to deck logs. Potentially, logs might be damaged during the decking process. Logs might sustain damage from grabbing a knuckle-boom loader by pinching or puncturing the logs rather than grabbing them whole. In Caspian region, a loader with a grapple attachment usually loads logs. Damage can be considered anything that detracts value from the harvested log or tree. This can include physical wounds to the logs caused by any of the harvesting functions, as well as excessive or insufficient trim or any other improper decision made during the log bucking process. Damage, however, will affect the potential value of logs that are going to be sold as saw logs and veneer logs to sawmill, or peeler logs to a wood composite facility.

Damage to hardwood logs is especially important in the Caspian hardwood forest region, where much of the hardwood timber harvested is sawn into grade lumber or turned into veneer or veneer-based composites. The objectives of this study were to: (1) measure log volume and value loss during bucking, skidding, loading or decking operations in Caspian hardwood sites, (2) identify how operational factors such as harvesting system, function, tree species and log size affect damage, and (3) suggest a model to estimate the damage probability of logs among harvesting systems, harvesting functions, tree species and log size.

Materials and methods

Volume and value loss during logging operations were studied with two harvesting systems including traditional and mechanized systems on four different Caspian hardwood forest sites. The data was analyzed by using Statistical Analysis Systems (SPSS). The general linear model (GLM) procedure, a type of analysis of variance (ANOVA), was used to determine whether there are significant differences among harvesting systems, harvesting functions, tree species and log sizes (Wang et al. 2004). The GLM can be expressed as follows:

$$\begin{cases} V_{ijklm} = \mu + HS_i + HF_j + SP_k + LS_l \\ \quad + HS_i \cdot SP_k + HF_j \cdot SP_k + HS_i \cdot LS_l \\ \quad + HF_j \cdot LS_l + SP_k \cdot LS_l + \varepsilon_{ijklm} \\ \quad i = 1,2; j = 1,2,3,4; k = 1,2,...,7; \\ \quad l = 1,2,...,5; m = 1,2,...,n \end{cases} \tag{1}$$

where, V_{ijklm} represents the mth observation of the volume or value loss for a log, μ the mean of response variable; HS_i the effect of ith harvesting system, HF_j the jth effect of harvesting function, SP_k the kth effect of species, LS_l the lth effect of log size, ε_{ijklm} is an error component for all uncontrolled variability, and n is the number of observations within each treatment. The interactions among harvesting systems, functions, tree species, and log sizes were also considered in the model.

The response variables were tested with Tukey's Test at the 5% level to determine whether there was any significant difference of damage volume and value loss among harvesting systems, functions, tree species and log sizes.

Results

Harvesting functions investigated included bucking, skidding, decking and loading. Two harvesting systems were analyzed: a traditional harvesting system based on chainsaw bucking, animal skidding, manual decking/loading; a mechanized system based on chainsaw bucking, skidding with a cable skidder, decking/loading with loader (Table 1). The operator's experience in using chainsaws varied from 5 to 16 years (Table 1).

Table 1. Harvesting machines and operators experience by site

Harvesting system	Site	Bucking		Skiding		Loading	
		machine	experince (year)	machine	experince (year)	machine	experince (year)
Mechanized	Site1	chainsaw	5	cable skidder	17	loader volvo	15
Traditional	Site 2	chainsaw	13	mule	16	manual	12
Mechanized	Site 3	chainsaw	16	cable skidder	5	loader volvo	6
Traditional	Site 4	chainsaw	7	mule	6	manual	9

The harvest sites were located in the north of Iran and had similar species composition, average slope and stand conditions (Table 2). The tract size ranged from 46−66 ha with average slopes of 20%–45%. Average residual stand density for the four tracts was approximately 171−197 trees·ha^{-1} with an average DBH ranging from 41.4–51.2 cm and an average merchantable height ranging from 10.5−13.1 m, respectively. Selective cuttings were conducted on all sites and harvest intensity was 20.8 m^3·ha^{-1}. The major species sampled were beech (*Fagus orientalis*), hornbeam (*Carpinus betulus*), alder (*Alnus subcordata*), maple (*Acer velutinum*) and elm (*Ulmus glabra*) (Table 2).

In addition to site and stand conditions, variables measured for each sawlog in the field included bottom and top diameter, length, tree species, damage type, damage location, damage dimensions, log grades, and comments for each individual log. Bottom and top diameters were measured in centimeters and the length of each sawlog was recorded in meter.

A total of 1,000 hardwood logs from four harvesting sites were sampled for measurable damage sustained during the harvesting operations. Of 1,000 observations per harvesting site, 250 observations were made for each of the four harvesting functions: bucking, skidding, decking and loading. Sampling was done by one function at a time. Damage was evaluated before and after each function to eliminate double counting of any damage caused by previous function. Bottom diameters of observed logs were between 73.4 and 96.9 cm, while top diameter varied from 21.1 cm to 31.3 cm. The length of observed logs ranged from 4.3 to 7.9 m and the log volume ranged from 1.01 to 1.45 m^3.

There were 79 logs that had wood damage and 460 logs that had bark damage, which accounted for 1.98% and 11.5% of the total 4,000 observed logs, respectively (Table 3). The damage

location was defined as general area where the damage occurred, whether at the bottom, middle or the top of the log. All damage including bark removal was recorded. However, for bark removal, there was no volume deduction. Damage volume was a volumetric measurement of the damage area and was calculated based on the length, width and depth of the damaged area at the greatest point. The grade of each log was determined based on the log's dimensions and the visual defects of the log (Carpenter et al. 1989; Hanks et al. 1980).

Table 2. Conditions for sites, harvests, and machines in the field study

	Harvest system	Harvest method	Harvest season	Slope (%)	Aspect	Total logs sampled	Tracy size (ha)	Stand density (trees/ha)	Species composition	Average merchantable height (m)	Average DBH (cm)
Site 1	mechanized	selective cut	winter-summer	35-39	N-NW	1000	46	197	Mixed-hardwoods	12.3	49.6
Site 2	traditional	selective cut	winter-spring	20-30	N-NW	1000	48	171	Mixed-hardwoods	10.5	45.9
Site 3	mechanized	selective cut	winter-summer	28-35	NE	1000	66	187	Mixed-hardwoods	11.4	41.4
Site 4	traditional	selective cut	winter-spring	39-45	NW	1000	52	176	Mixed-hardwoods	13.1	51.2

Table 3. Damage distributions of observed logs and log attributes by species

Species	Number of observed logs					Average size of observed logs			
	Percent*	No damage	Bark damage	Wood damage	Damage (%)	Bottom diameter (cm)	Top diameter (cm)	Length (m)	Volume (m^3)
Beech	69	321	77	19	5.1	88.8	21.1	4.8	1.14
Hornbeam	12	193	97	10	3.2	77.2	25.5	4.9	1.01
Elm	3	221	181	22	6.5	96.9	31.3	4.5	1.4
Maple	9	344	49	23	4.4	91.9	22.7	4.3	1.11
Alder	7	210	56	5	2.3	73.4	23.5	7.9	1.45

*Percent proportion is based on the number of logs sampled

Sawlog damage was analyzed in terms of volume and value losses. Volume loss was computed based on the damage dimensions. Pre- and post-damage log grades were given to all logs based on their dimensions, superficial condition and damage severity. Damage volume was deducted from a log with slight damage while both volume deduction and degradation were considered for a severely damaged log. A log pricing system was developed based on current sawlog market prices from the local hardwood lumber industry and Tehran (Capital city of Iran) timber market reports (Emanuel and Rhodes 2002). A monetary value was assigned to the log based on its volume, species, grade and current hardwood sawlog market prices. This system then assigned a post-damage volume loss and monetary value to each log based on the amount of damage the log had sustained. Each log then had a pre-damage and a post-damage monetary value associated with it. Monetary value loss was determined by calculating the difference between the pre-damage value and the post-damage value. Log size was computed based on its volume and grouped into five different categories of 1.0, 1.1, 1.2, 1.3, and 1.4 m^3. In order to compare the log damage, percentage of volume loss, value loss per cubic meter, and percentage of value loss were defined and computed based on the ratios of damage volume over log volume, value loss over log volume and value loss over log value, respectively.

Gouge was the most common damage type in the field study. However, splits and slabbing caused the most volume and value losses to logs. Splits caused losses of 8.2 $\$\cdot m^{-3}$ for the damaged logs and resulted in 6.9% and 7.1% of volume and value losses, while slabbing resulted in 6.5% volume loss and 6.2% value loss or 5.2 $\$\cdot m^{-3}$ in value loss (Table 4). Most damage, about 41%, occurred at the bottom parts of logs. Damage at the bottom of the logs resulted in losing 3.8% in log's volume and value or 5 $\$\cdot m^{-3}$. It was followed by damage at the middle of the log with 1.5% value loss and volume loss or 1.6 $\$\cdot m^{-3}$ value loss. Harvesting in site 4 presented relatively higher damage rates to logs (36.7%) in comparison with the damage rates of 18.8% in site 1, 8.5% in site 2 and 35.9% in site 3 (Table 4). However, animal skidding caused more volume and value losses in sites 2 and 4 (Table 4).

Table 4. Volume and value losses per log by damage type, location and site

	Number of logs	Volume loss		Value loss		
		Per log (m^3/1000)	Percent of log volume (%)	Per log ($/log)	Per volume unit ($/$m^3$)	Percent of log value (%)
Type						
Gouge	145	6.5	1.1	1.2	2.0	1.6
Slab	76	23.7	6.5	2.7	5.2	6.2
Split	89	38.4	6.9	6.9	8.2	7.1
Scrape	43	2.0	0.3	1.2	1.8	2.4
Choker	53	17.7	2.5	6.3	8.5	5.9
Location						
Bottom	162	12.1	3.8	3.3	5.0	3.8
Middle	45	8.1	1.5	0.8	1.6	1.5
Top	19	4.9	1.3	0.7	1.4	1.3
Site						
1	75	7.3	1.9	0.8	1.7	2.0
2	34	72.1	16.2	9.3	16.5	17.2
3	143	36.2	9.7	4.3	6.2	9.2
4	146	19.9	27.4	18.8	29.8	34.7

The percentage of volume loss and the percentage of value loss, or value loss per cubic meter were significantly different between two harvesting systems. Mechanized systems caused a loss equal to 13.9% of a log's volume and 6.3% of value loss or 6.0 $\$\cdot m^{-3}$, while traditional systems lost 40.5% of volume and 39.0% of value or 89.5 $\$\cdot m^{-3}$ (Table 5). Bucking damage caused 9.9% volume loss of the logs and 7.1% of value loss or 5.5 $\$\cdot m^{-3}$, which differed significantly from the damage caused during skidding, decking and loading operations. However, log damage was not significantly different among skidding, decking, and loading operations (Table 5).

Table 5. Means and significance levels of operational variables associated with damaged logs*

	Volume loss		Value loss		
	Per log (m^3/1000)	Percent of log volume (%)	Per log (\$/log)	Per volume Unit (\$/m^3)	Percent of log value (%)
Harvest system					
Traditional	42.1a	40.5a	74.6a	89.5a	39.0a
Mechanized	16.6b	13.9b	3.6b	6.0b	6.3b
Harvest functions					
Bucking	8.9c	9.9c	5.1c	5.5c	7.1c
Skidding	1.3d	0.2d	0.1d	0.2d	0.2d
Decking	1.5d	0.4d	0.2d	0.2d	0.4d
Loading	0.9d	0.3d	0.1d	0.2d	0.2d
Species					
Beech	3.1e	1.6e	2.1f	2.6f	2.0e
Hornbeam	2.0e	0.6e	0.1e	0.2f	0.5e
Alder	8.4f	1.6f	0.5f	0.8f	0.7e
Maple	5.1f	2.8f	4.1e	5.3e	4.2f
Elm	2.3e	1.4e	4.5g	7.6g	8.9g
Log size (m^3)					
1	9.0h	4.7h	0.5h	2.3h	9.0h
1.1	10.0h	2.5hi	1.7hi	1.1h	2.5hi
1.2	8.9h	1.5i	1.3i	2.1h	1.4i
1.3	3.6h	0.5i	0.6hi	0.7h	0.5i
1.4	6.2h	0.4i	0.9hi	0.6h	0.4i

Means with the same letter in a column are not significantly different at the 0.05 with Tukey's Test

The percentage of damaged logs by species ranged from 2% for hornbeam to 8.4% for alder (Table 5). The damage to beech resulted in 1.6% loss of the volume and 2.6 $\$\cdot m^{-3}$ value loss (2.0% of log's value), and also the damage to elm resulted in 1.4% volume loss and 7.6 $\$\cdot m^{-3}$ value loss (8.9% of log's value) (Table 5). Volume loss of damaged logs was not significantly different between alder and maple but was significant among these two species (alder and maple) with other species (beech, elm, and hornbeam) while the values loss did not differ significantly among beech, alder and hornbeam (Table 5).

The percentage of volume and value losses varied increasingly as the log size decreased from 0.4% of 1.4 m^3 logs to 4.7% of 1 m^3 logs (Table 5). Value loss was between 0.6 $\$\cdot m^{-3}$ of 1.15 m^3 logs and 2.3 $\$\cdot m^{-3}$ of 0.46 m^3 logs, and generally decreases with the log size. The log size affected percentages of volume loss and value loss significantly. However, the volume loss per damaged log and the value loss per cubic meter were not sensitive to log size.

The percentages of volume loss and value loss were significantly affected by the interactions of harvesting system and tree species, and harvesting system and log size. However, all the interactions did not significantly affect the value loss per cubic meter for the damaged logs.

Discussion

Our study provides volume and value loss during harvesting in Caspian forest sites. The results showed that Most damage occurred at the bottom parts of the logs resulted in losing 3.8% in log's volume and value or 5\$/m^3, this is mainly because the bottom section of the log is usually the location where the chokers are fixed. On the other hand, damage rates to logs in site 4 are higher (36.7%) in comparison with the damage rates in sites 1, 2, and 3 (Table 4). This higher damage might be because of the difficult terrain (slope: 39%–45%) and less experienced operators of the felling (7 years) and skidding machines on site 4. As shown in Table 5, the majority of the value loss was caused during the bucking function (5.5 $\$\cdot m^{-3}$) when using a traditional harvesting system (89.5 $\$\cdot m^{-3}$) on difficult terrain. The damage caused by bucking operations in traditional harvesting system overshadows damage from all other parts of the timber harvesting process. Improper bucking may not damage the log in a physical sense, but it can damage the potential value gained from bucking correctly (Sessions 1988; Pickens et al. 1992) and can be definitely a serious problem (Zavala 1992). Results suggest that logs skidding, decking and loading have very little impact on damage levels (Table 5). Even though the damage from bucking in traditional harvesting system by far exceeds any other damage observed in our study, the value loss associated with the mechanized harvesting system is less.

Except for alder, and maple all other major hardwood species in this region consisting of beech, hornbeam, and elm showed similar volume loss (Table 5). Alder and maple presented a significant difference in volume loss compared to the other three species observed. One reason for this could be the mechanical properties of Alder and maple. It has been suggested in past studies that more brittle species (such as alder and maple) have a greater susceptibility to damage than other species (such as beech, elm and hornbeam) showing more resistance. Another reason for differences among species could be the harvest time. Although, in our study all observations were made during the winter, spring and summer.

The damage to sawlogs is occurring during harvesting operations (Pickens et al. 1992), but to a lesser degree that might be perceived by the wood products industry. Certainly, there is room for improvement of motor-manual felling operations. This could be accomplished by formal chainsaw felling instruction and by paying more attention to value and grade, rather than volume alone (Sessions 1988). The damage to logs is likely to vary from

site to site, and maybe even within a single site. These variations may be driven by geographic factors, not considered in our study, which focused on north of Iran.

The information from the field study is important in creating new guidelines or training to help minimize hardwood log damage occurring during the timber harvesting process. It would be beneficial to determine how log damage relates to skid trail density, road capacity, multiple landings and their locations, and the length of skid. Additionally, terrain slope could be analyzed more closely, especially its correlation with the occurrence of switchbacks that may damage logs.

Implementing new and better guidelines or training requirements for fellers could create monetary gains for loggers while better utilizing the forest resources by not damaging valuable hardwood logs in Caspian forests. We recommend the further value recovery studies be undertaken to broaden the knowledge base in this area.

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